

SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT I, AKIHIKO SHIMIZU, a
citizen of Japan residing at Kanagawa, Japan have
invented certain new and useful improvements in

METHOD FOR OPTICALLY RECORDING INFORMATION

of which the following is a specification:-

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to a method for optically recording information and more particularly a method for optically recording information in which a multi level signal is recorded on a track.

2. Description of the Related Art

The Japanese Laid-Open Patent Application No.8-147695 (a prior art method ①) discloses such kind of technology. In the prior art method ①, although the power of a laser diode is not decided in an ALPC zone, the laser diode is driven by a simple low bandwidth drive circuit with a multiple level drive current. First, the laser diode is driven on a trial basis in a Test Zone or a Manufacturer Zone, which zones are placed at an inside and an outside of an optical disc, and each zone has more than 100 tracks. In these zones, first, the laser diode is driven by the drive circuit having a current level of I_{w0} . Next, the laser diode is driven by the drive circuit having a current level of I_{w1} . Then, the laser diode is driven by the drive circuit having a current level of I_{w2} . Then, each current level of I_{w0} , I_{w1} and

Iw2 is optimally determined for predetermined power levels, respectively. When information is written on the disc in a write mode, first, a w0 D/A converter is supplied with data for the current
5 value Iw0, a w1 D/A converter is supplied with data for the current value Iw1 and a w2 D/A converter is supplied with data for the current value Iw2. Then, switches SW4, SW5 and SW6 are turned on or turned off according to the data to be written. As a
10 result, the laser diode LD1 is supplied with the LD drive current.

The Japanese Laid-Open Patent Application No.11-25456 (a prior art method ②) also discloses such kind of technology. The prior art method ②
15 discloses a simple method for recording multi level information on an optical information medium in order to raise recording density. In the prior art method ②, initially, first pits are formed on a re-writable media (a phase change optical disc) by
20 radiating a laser light. Then, second pits are formed on the first pits by erasing parts of the first pits according to a multi leveled signal of the information to be recorded. Sizes of the second pits are modulated according to the multi level
25 information.

Fig.1 shows an example of a waveform of a recording pulse signal according to the prior art method ① as described above. The waveform of the recording pulse signal is composed of a rectangular recording pulse and an erasing pulse. A means for adjusting the size of a recorded mark controls the width of the recording pulse ($T_3 - T_1$ as shown in Fig.1) or strength of a light (P_w as shown in Fig.1). On reproducing the recorded marks, strength of a reflected light by the mark is varied according to the size of the recorded mark. Therefore, a multi level signal, which is converted from the light reflected and has one of MARK signal levels corresponding to the size of the recorded mark, can be obtained as shown in Fig.2. Fig.2 shows a principle of such multi level recording method using a recorded mark size modulation .

A disadvantage of this method using the waveform of the recording pulse signal composed of the rectangular recording pulse and the erasing pulse is that the recorded mark is apt to be enlarged in the radial direction because of thermal diffusion caused by the laser beam focused on the optical information medium. Therefore, the shape of the recorded mark is apt to have a shape like a drop

of water as shown in Fig.1. Therefore, this method can not control the influence of the thermal diffusion on the size of the recorded mark if the size of the mark smaller than the size of the focused laser beam spot is formed.

Fig.3 shows a relation between an occupied mark ratio and a multi level mark signal level according to the prior art method ①. As shown in Fig.3, at a region ① in which the mark signal level is relatively high, a ratio of the mark signal level variation to the occupied mark ratio variation is high compared to that at a region ② in which the mark signal level is relatively low. Therefore, there is a need to control the occupied mark ratio more precisely at the region ① than at the region ②. However, the prior art method ① as shown in Fig.1 cannot control the occupied mark ratio accurately because it cannot control the influence of the thermal diffusion to the size of the recorded mark. Therefore, the prior art method ① cannot control each level of the multi level signal accurately.

Fig.5 shows the prior art method ②. To eliminate the disadvantage of the prior art method ①, it is possible to use a recording pulse signal

composed of multi pulses as shown in Fig.5. In this prior art method ②, the recording pulse is composed of a start pulse, short multi pulses and an erasing pulse. As the short multi pulses are used, the
5 enlargement of the recorded mark in the radial direction caused by thermal diffusion can be prevented. A means for adjusting the size of the recorded mark controls the width of the first pulse ($T_2 - T_1$ as shown in Fig.5), the duty of the multi
10 pulses ($T_4 - T_3$ as shown in Fig.5), or strength of the first pulse and the multi pulses (P_w as shown in Fig.5).

There is a need to raise the frequency of the recording pulses to form the recorded marks
15 having a size less than that of the focused laser beam spot. Therefore, a recording pulse generation circuit and a laser diode need to be operated at a high frequency in order to record the information on the optical information medium at a high speed.
20 However, it is hard to raise their operating frequencies. Further, the recording pulse generation circuit becomes complex.

SUMMARY OF THE INVENTION

25 It is a general object of the present

invention to provide a method for optically recording information in which the above disadvantages are eliminated.

Further, it is another object of the present invention to provide a method for optically recording information in which recorded marks having a size less than that of a focused laser beam spot can be formed using a multi level signal recording method with a recording pulse having a simple waveform.

Further, it is another object of the present invention to provide a method for optically recording information in which the size of each recorded mark having a size less than that of a focused laser beam spot can be controlled to a desired size.

Further, it is another object of the present invention to provide a method for optically recording information in which a position of the recorded mark having a size less than that of a focused laser beam spot is controlled precisely by a simple method for controlling the recording pulse.

Further, it is another object of the present invention to provide a method for optically recording information in which a size of the

recorded mark having the size less than that of a focused laser beam spot is fine-tuned accurately.

Further, it is another object of the present invention to provide a method for optically
5 recording information in which the position of the recorded mark having a size less than that of a focused laser beam spot is fine-tuned accurately.

Further, it is another object of the present invention to provide a method for optically
10 recording information in which each level of the multi level signal is recorded accurately.

The above objects of the present invention are achieved by a method for optically recording information on an optically re-writable information
15 medium having at least one track, in which method a laser light is focused to a laser spot to form a mark on the optically re-writable information medium and the size of the mark is modulated according to a level of a multi-level signal which correspond to
20 the information to be recorded, further in which method:

the strength of the laser light for recording each mark is modulated according to a waveform comprising a first rectangular erasing
25 pulse signal, a rectangular recording pulse signal,

an off-pulse signal and a second rectangular erasing pulse signal,

the laser light having a strength set to a value indicated by the first rectangular erasing pulse signal can erase a recorded mark,

the laser light having a strength set to a value indicated by the rectangular recording pulse signal can record a mark,

the strength of the laser light set to a value indicated by the off-pulse signal is less than the strength of the laser light used in reproduction of the recorded marks,

the laser light having a strength set to a value indicated by the second rectangular erasing pulse signal can erase the recorded mark, and

a product of the time interval of the rectangular recording pulse signal and the relative linear velocity between the laser spot and the optically re-writable information medium is shorter than the length of the recorded mark.

According to the present invention, the mark is formed on a recording medium by radiating the laser light having the strength of the short recording pulse signal followed by the off-pulse signal. The recording film is heated to form the

mark and the mark is extended by a thermal diffusion while the off-pulse signal is provided. Therefore, the length of the recorded mark ML is longer than the recording pulse width at the predetermined
5 linear velocity. The erasing pulse signal follows the off-pulse signal and the extended recorded mark is erased by the erasing pulse signal.

The recording method according to the present invention can form a mark on the recording
10 medium by radiating the laser light having a shorter recording pulse width than a recording pulse width used in the conventional method to form a mark having the same length. Therefore, heat quantity applied to the medium by the recording method
15 according to the present invention is smaller than that of the conventional method. As a result, expansion of the mark in a direction perpendicular to the longitudinal direction of the track is reduced compared to the conventional methods.

20 The above objects of the present invention are achieved by a method for optically recording information on an optically re-writable information medium, wherein the size of the mark is modulated according to the information by means of modulating
25 a pulse width of the off-pulse signal so that the

time interval between a rising edge of the rectangular recording pulse signal and a rising edge of the rectangular erasing pulse signal corresponds to the size of the mark.

5 According to the present invention, a simple recording pulse signal generation circuit can be used for multi-level recording because the size of the mark is modulated according to the information by means of modulating only the pulse
10 width of the off-pulse signal.

 The above objects of the present invention are achieved by a method for optically recording information on an optically re-writable information medium, wherein the track is divided into a
15 plurality of cells and the mark is recorded in the cell so that the center of the mark is placed at the center of the cell by means of adjusting both the rising edge of the rectangular recording pulse signal and the rising edge of the rectangular
20 erasing pulse signal.

 According to the invention, the center of the mark is precisely placed at the center of the cell by means of adjusting both the rising edge of the rectangular recording pulse signal and the
25 rising edge of the rectangular erasing pulse signal

because the effect of the thermal diffusion is effectively used.

The above objects of the present invention are achieved by a method for optically recording
5 information on an optically re-writable information medium, wherein the size of the mark is fine-adjusted by controlling the timing of a falling edge of the rectangular recording pulse signal.

According to the invention, the size of
10 the mark is fine-adjusted by controlling only the timing of the falling edge of the rectangular recording pulse signal because the effect of the thermal diffusion is effectively used.

The above objects of the present invention
15 are achieved by a method for optically recording information on an optically re-writable information medium, wherein the size of the mark is fine-adjusted by controlling the strength of the laser light modulated by the rectangular recording pulse
20 signal.

According to the present invention, the size of the mark is fine-adjusted by controlling only the strength of the laser light modulated by the rectangular recording pulse signal because the
25 effect of the thermal diffusion is effectively used.

The above objects of the present invention are achieved by a method for optically recording information on an optically re-writable information medium, wherein the timing of the rising edge of the rectangular recording pulse signal is controlled so
5 that the center of the mark is placed at the center of the cell.

According to the invention, the center of the mark is precisely placed at the center of the
10 cell by only further shifting the rectangular recording pulse signal because the effect of the thermal diffusion is effectively used.

The above objects of the present invention are achieved by a method for optically recording
15 information on an optically re-writable information medium, wherein the relation between the length (ML) of the mark along the track and a diameter (BD) of the laser spot satisfies $ML \leq BD$, and

the product of the pulse width of the
20 rectangular recording pulse signal and the relative linear velocity is less than 20 % of the diameter (BD) of the laser spot.

According to the present invention, the width of the rectangular recording pulse signal is
25 properly limited so that the mark can be recorded

with higher precision.

The above objects of the present invention are achieved by a method for optically recording information on an optically re-writable information medium, wherein the relation between the length of a
5 minimum mark (MLmin) along the track, except when there is no mark, and the diameter (BD) of the laser spot satisfies $MLmin / BD \geq 0.10$, and

each level of the multi-level signal is
10 assigned so that the level difference between adjacent levels becomes equidistant, except when there is no mark.

According to the present invention, the deviation from the aimed multi-level signal levels
15 can be reduced.

The above objects of the present invention are achieved by a method for optically recording information on an optically re-writable information medium, wherein
20 the relation between the length of a maximum mark (MLmax) along the track, except for a mark that has about the same length as a diameter of the laser spot, and the diameter (BD) of the laser spot satisfies $MLmax / BD \leq 0.70$, and

25 each occupied mark ratio of the multi-

level signal is assigned so that the difference
between the occupied mark ratios corresponding to
adjacent levels of the multi-level signal becomes
equidistant, except for the mark that has about the
5 same length as the diameter of the laser spot.

According to the present invention, the
deviation from the aimed multi-level signal levels
can be reduced.

10 BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of
the present invention will become more apparent from
the following detailed description when read in
conjunction with the accompanying drawings, in
15 which:

Fig.1 shows an example of a waveform of a
recording pulse signal according to the prior art
method ①;

Fig.2 shows a principle of a multi level
20 recording method using a recorded mark size
modulation according to the prior art;

Fig.3 shows a relation between an occupied
MARK ratio and a MARK signal level according to the
prior art method ①;

25 Fig.4 shows measured deviation values from

aimed multi-level signal levels according to the
prior art method ①;

Fig.5 shows an example of a waveform of a
recording pulse signal according to the prior art
5 method ②;

Fig.6 shows an example of a basic waveform
of a recording pulse signal according to an
embodiment of the present invention;

Fig.7 shows a waveform of a recording
10 pulse signal of a first method for controlling the
width of a recorded mark in a direction
perpendicular to a longitudinal direction of a track
according to an embodiment of the present invention;

Fig.8 shows a waveform of a recording
15 pulse signal of a second method for controlling the
width of a recorded mark in a direction
perpendicular to the longitudinal direction of the
track according to an embodiment of the present
invention;

Fig.9 shows a waveform of a recording
20 pulse signal of a third method for controlling the
width of a recorded mark in a direction
perpendicular to the longitudinal direction of the
track according to an embodiment of the present
25 invention;

Fig.10 shows a waveform of a recording pulse signal of a fourth method for controlling the width of a recorded mark in a direction perpendicular to the longitudinal direction of the track according to an embodiment of the present invention;

Fig.11 shows a waveform of a recording pulse signal of a first method for controlling the start point of a recorded mark according to an embodiment of the present invention;

Fig.12 shows a waveform of a recording pulse signal of a second method for controlling the start point of a recorded mark according to an embodiment of the present invention;

Fig.13 shows a waveform of a recording pulse signal of a third method for controlling the start point of a recorded mark according to an embodiment of the present invention;

Fig.14 shows a waveform of a recording pulse signal of a fourth method for controlling the start point of a recorded mark according to an embodiment of the present invention;

Fig.15 shows relations between waveforms of recording pulse signals and recorded marks according to an embodiment of the present invention;

Fig.16 shows a block diagram of an optical information recording apparatus according to an embodiment of the present invention;

Fig.17 shows a result of recording and reproducing information on a disc according to an embodiment of the present invention;

Fig.18 shows measured deviation values from aimed multi-level signal levels according to an embodiment of the present invention;

Fig.19 shows a relation between a MARK signal level of a multi level RF signal and an occupied MARK ratio;

Fig.20 shows a relation between a MARK signal level of a multi level RF signal and an occupied MARK ratio;

Fig.21 shows a relation between an occupied MARK ratio and a MARK signal level of a multi level RF signal;

Fig.22 shows a relation between an occupied MARK ratio and a MARK signal level of a multi level RF signal;

Fig.23 shows relation between the mark levels and the occupied mark ratios (ML/BD);

Fig.24 shows the relation between the mark levels and the occupied mark ratios;

Fig.25 shows the relation between the occupied mark ratios and the mark levels; and

Fig.26 shows the relation between the occupied mark ratio and the mark level difference Δ
5 S.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Next, an embodiment according to the present invention will be explained with reference
10 to accompanying figures.

1. Principle of recording

Fig.6 shows a waveform of a recording pulse signal according to the present invention. The waveform of the recording pulse signal, by means
15 of which strength of a laser light supplied from a laser diode is modulated, consists of a first rectangular erasing pulse signal, a rectangular recording pulse signal, an off-pulse signal and a second rectangular erasing pulse signal, and these
20 four kinds of pulse signals are repeated for each mark. The laser light having the strength that is set to a value indicated by the first rectangular erasing pulse signal can erase a recorded mark. The laser light having the strength that is set to a
25 value indicated by the rectangular recording pulse

signal can form a mark. The strength of the laser light used in reproduction of the recorded marks is set to a value less than the value of the rectangular recording pulse by means of the off-pulse signal. The laser light having the strength which is set to a value indicated by the second rectangular erasing pulse signal can erase a recorded mark. A track is divided into cells in a longitudinal direction. Each cell corresponds to a time interval T_5 at a predetermined linear velocity as shown in Fig.6. Length of a mark ML recorded in a cell along the track can be controlled by recording pulse width ($T_2 - T_1$) and a start point of the erasing pulse signal T_4 . If the length of the mark to be recorded is changed, a time T_1 and the time T_4 are adjusted to record the mark at the center of the cell. For example, if the length of the recorded mark is changed from ML to ML' , then T_1 should also be changed to $T_1 + s$ and T_4 should also be changed to $T_4 - s$ to record the mark at the center of the cell.

The mark ML is formed on a recording medium by radiating the laser light having the strength of the recording pulse signal during the time interval $T_2 - T_1$. The recording film is heated

to form the mark and the mark is extended by thermal diffusion while the off-pulse signal is provided.

Therefore, the length of the recorded mark ML is longer than the recording pulse width at the

5 predetermined linear velocity. The erasing pulse signal follows the off-pulse signal and the extended recorded mark is erased by the erasing pulse signal. As a result, the marks ML as shown in Fig.6 are formed on the recording medium.

10 The recording method according to the present invention can form a mark on the recording medium by radiating the laser light having a shorter recording pulse width ($T_2 - T_1$) than the recording pulse width used in the conventional method to form
15 a mark having the same length. Therefore, heat quantity applied to the medium by the recording method according to the present invention is smaller than that of the conventional method. As a result, expansion of the mark in a direction perpendicular
20 to the longitudinal direction of the track is reduced compared to the conventional methods. The present invention has such an advantage. Further, the size of the recorded mark can be controlled by means of changing the off-pulse width according to
25 each level of a desired multi-level signal based on

the principle of the present invention.

2. Controlling the mark width in a direction perpendicular to the longitudinal direction of the track

5 As described above, by limiting the effect of the thermal diffusion, it is possible to control the mark width in a direction perpendicular to the longitudinal direction of the track. The thermal quantity applied by the laser light radiated to the
10 medium is controlled to limit the extension of the mark.

 Fig.7 through Fig.10 show a method to control the mark width in a direction perpendicular to the longitudinal direction of the track. As
15 shown in Fig.7, the mark width is extended as the recording pulse width is extended from the time interval T_2 to the time interval T_{21} , where T_{21} is greater than T_2 . The mark A is recorded with a recording pulse T_2 and the mark B is recorded with a
20 recording pulse T_{21} .

 On the contrary, as shown in Fig.9, the mark width is reduced as the recording pulse width is reduced from the time interval T_2 to the time interval T_{22} , where T_{22} is shorter than T_2 . The
25 mark A is recorded with a recording pulse T_2 and the

mark B is recorded with a recording pulse T22.

As shown in Fig.8, the mark width is extended as the strength of the laser light is raised from PW1 to PW2, where PW2 is greater than
5 PW1. The mark A is recorded with the laser light having the strength of PW1 and the mark B is recorded with the laser light having the strength of PW2.

On the contrary, as shown in Fig.10, the
10 mark width is reduced as the strength of the laser light is reduced from PW1 to PW3, where PW3 is lower than PW1. The mark A is recorded with the laser light having the strength of PW1 and the mark B is recorded with the laser light having the strength of
15 PW3.

3. Controlling the position of the recorded mark

As described above, the thermal quantity applied by the laser light radiated to the medium is
20 controlled to limit the extension of the mark in the direction perpendicular to the longitudinal direction of the track. As a result, the start point of the recording mark formed on the medium is also changed. Therefore, the relative position
25 between the recorded mark and the center of the cell

is changed.

Therefore, the mark position recorded along the track also needs to be controlled when the mark width is controlled. Fig.11 through Fig.14
5 shows several methods to control the start position for recording the mark.

As shown in Fig.11, the start point of the recording pulse signal is modified from T_1 to T_1+s and the end point of the recording pulse signal is
10 modified from T_{21} to $T_{21}+s$ to correct a forward variation s of the start point without changing the pulse width $T_{21} - T_1$.

As shown in Fig.13, the start point of the recording pulse signal is modified from T_1 to T_1-s
15 and the end point of the recording pulse signal is modified from T_{22} to $T_{22}-s$ to correct a backward variation s of the start point without changing the pulse width $T_{22} - T_1$.

As shown in Fig.12, the start point of the
20 recording pulse signal is modified from T_1 to T_1+s and the end point of the recording pulse signal is modified from T_2 to T_2+s to correct a forward variation s of the start point without changing the pulse width $T_2 - T_1$.

25 As shown in Fig.14, the start point of the

recording pulse signal is modified from T1 to T1-s
and the end point of the recording pulse signal is
modified from T2 to T2-s to correct a backward
variation s of the start point without changing the
5 pulse width T2 - T1.

Fig.15 shows relations between waveforms
of recording pulse signals and recorded marks
according to an embodiment of the present invention.

4. Embodiment ① of recording and 10 reproduction

Fig.16 shows a block diagram of an optical
information recording apparatus according to an
embodiment of the present invention. In this
embodiment ①, the information is recorded and
15 reproduced on an optical recording medium 1 by the
optical information recording apparatus. The
optical information recording apparatus as shown in
Fig.16 has a spindle motor (not shown), a laser
diode 2, a collimator lens 3, a polarizer 4, an
20 objective lens 5, a detection lens 6, a quadrant
photo detector 7 and actuators 8. The light
radiated from the laser diode 2 is focused on the
optical recording medium 1 through the collimator
lens 3, the polarizer 4 and the objective lens 5,
25 and then, the marks are recorded on the optical

recording medium 1. The reflected light is polarized by the polarizer 4 and focused on the quadrant photo detector 7 through the detection lens 6. Then, an RF signal is detected by the quadrant photo detector 7. The actuators 8 control the position of the objective lens 5 both for focusing the laser spot on the medium and for moving the laser spot to follow the track. A wavelength λ of the laser for recording or reproduction is 650 nm and a numerical aperture NA is 0.65. As a result, the diameter of the laser beam spot is 0.8 μm . These parameters are commonly used in a typical re-writable DVD recording apparatus. The optical recording medium 1 is composed of a phase change material such as AgInSbTe, which is a re-writable type material. The marks are recorded on a groove track and a distance between the adjacent tracks, which is called a track pitch, is 0.74 μm and the track width is about 0.4 μm . Recording conditions are as follows. The recording power is 14 mW on the recording surface, the erasing power is 7.5 mW and the relative linear velocity between the groove track and the laser light spot is about 3.5 m/s. The length of the cell is about 0.7 μm along the groove track.

Fig.17 shows a result of recording and reproducing information on the optical recording media 1 according to an embodiment of the present invention. In Fig.17, the abscissa shows a ratio of
5 a recording pulse width ($T_2 - T_1$) to a beam spot diameter BD and the ordinate shows a sum signal that is called the RF signal. The RF signal is generated by means of opto-electrically converting a light reflected from the recorded mark to an electrical
10 signal. The curve Lv1 in Fig.17 shows a case when the rising edge T_1 of the recording pulse signal and the falling edge T_2 of the erasing pulse signal are adjusted so that the mark length of the recorded mark ML becomes $0.13 \mu\text{m}$. The curve Lv2 in Fig.17
15 shows a case when the rising edge T_1 of the recording pulse signal and the falling edge T_2 of the erasing pulse signal are adjusted so that the mark length of the recorded mark ML becomes $0.27 \mu\text{m}$. The curve Lv3 in Fig.17 shows a case when the rising
20 edge T_1 of the recording pulse signal and a the falling edge T_2 of the erasing pulse signal are adjusted so that the mark length of the recorded mark ML becomes $0.40 \mu\text{m}$.

Fig.17 shows that the RF signal value
25 (Mark signal level) for each curve is saturated at a

range of the recording pulse width ratio $(T2 - T1)/BD$ between 0.16 to 0.20. This is because the maximum mark width in a direction perpendicular to the longitudinal direction of the track is limited
5 to the groove track width.

These data mean that the RF signal level (Mark signal level) can be fine-adjusted as long as the recording pulse signal ratio of $(T2 - T1)/BD$ is kept less than 0.20.

10 5. Embodiment ② of recording and reproduction

This embodiment ② shows deviation values from aimed multi-level signal levels.

Fig.18 shows measured deviation values
15 from aimed multi-level signal levels according to an embodiment ② of the present invention. On the other hand, Fig.4 shows measured deviation values from aimed multi-level signal levels according to the prior art method ①. The recording condition
20 used in this embodiment ② is the same condition as that used in the embodiment ①.

As described for the prior art methods, at the region ① as shown in Fig.3 in which a mark signal level is relatively high, the mark signal
25 level variation to the occupied mark ratio variation

is high compared to that at the region ② in which a mark signal level is relatively low. In the prior art methods, the maximum deviation (σ) to the aimed multi-level signal level is about 8 %.

5 On the contrary, the result from this embodiment ② shows that the maximum deviation (σ) to the aimed multi-level signal level at the region ① is about 2 %. This means that the method according to the present invention is superior to
10 the prior art methods.

6. Embodiment ③ for determining levels of a multi-level signal

In the multi-level signal recording method in which a size of the recorded mark is changed
15 according to the signal level, it is important to select a condition of the mark length, under which the mark is easily recorded in order to easily detect the multi-level RF signal correctly. Fig.19 and Fig.20 show the relation between the multi-level
20 RF signal level (Mark signal level) and the occupied mark ratio. The abscissa shows the multi-level RF signal level (Mark signal level) and the ordinate shows the occupied mark ratio.

As shown in Fig.19, a range of the mark
25 signal level between 0.4 and 1.0 can be used to

express the multi-level signal. The black dots show 8 multi-levels. The distances between the adjacent levels are equal to each other. Fig.23 shows the relation between the mark levels and the occupied mark ratios (ML/BD) shown in Fig.19.

As shown in Fig.23, the occupied mark ratio difference ΔL is 0.04 between the mark levels of 1.00 and 0.91. Therefore, there is little margin in the precision for forming the mark ML. On the other hand, the occupied mark ratio difference ΔL is more than 0.1 between the mark levels of 0.40 and 0.66. Therefore, there is much margin in the precision for forming the mark ML.

An embodiment ③ is shown in Fig.24. Fig.24 shows the relation between the mark levels and the occupied mark ratios, in which the margin in the precision for forming the mark is raised for higher mark levels. In the Fig.24, the occupied mark ratio difference ΔL is raised to about twice the occupied mark ratio difference ΔL as shown in Fig.23 for higher mark levels. The minimum occupied mark ratio for the mark level of 0.80 is set to 0.12 in Fig.24. The mark level of 1.00 is ruled out because there is no mark for the mark level of 1.00. As a result, 7 mark levels are equidistantly

assigned between the mark level of 0.40 and 0.80 in Fig.24. Therefore, the minimum occupied mark ratio for the cell, except for the cell without mark having the mark level of 1.00, can be set more than 0.1 so that the margin of ΔL is leveled and the deviation from the aimed multi-level signal can be reduced.

7. Embodiment ④ for determining levels of a multi-level signal

10 As mentioned above, in the embodiment ③, the method for enhancing the margin of ΔL , in which method the minimum occupied mark ratio for the mark level can be set more than 0.1 so that the margin of ΔL is leveled, is described. In this embodiment ④, 15 a method for reducing the deviation of the multi-level signal from the aimed multi-level signal while the margin of ΔL is leveled, is described. Both Fig.21 and Fig.22 show the relation between the occupied mark ratio (ML/BD) and the mark signal level. 20 An abscissa shows the occupied mark ratio (ML/BD) and an ordinate shows the mark signal level.

As shown in Fig.21, each mark level of 8 mark levels is assigned so that the occupied mark ratio is between 0 to 1.0 and ΔL is equidistantly 25 assigned. Fig.25 shows the relation between the

occupied mark ratios and the mark levels under the condition mentioned above in Fig.21.

As shown in Fig.25, the mark level difference ΔS is 0.01 between the occupied mark ratios of 0.71 and 1.00. There is little margin in the precision for forming the mark ML.

An embodiment ④ is shown in Fig.26. Fig.26 shows the relation between the occupied mark ratio and the mark level difference ΔS , in which the margin of ΔS is raised compared to Fig.25.

As shown in Fig.26, the maximum occupied mark ratio is set to 0.70. The mark level of 1.00 is ruled out because the cell is filled with the mark for the mark level of 1.00. As a result, 7 mark levels are equidistantly assigned between the occupied mark ratios of 0 and 0.70. Therefore, ΔS is leveled and the minimum value of ΔS is improved to 0.05.

As described above, the maximum occupied mark ratio can be set to 0.70 so that the margin of ΔS is leveled and the deviation of the multi-level signal from the aimed multi-level signal can be reduced.

The present invention is not limited to the specifically disclosed embodiments, and

variations and modifications may be made without departing from the scope of the present invention.

The present application is based on Japanese priority application No.2001-036395 filed
5 on February 14, 2001, the entire contents of which are hereby incorporated by reference.